

The Andesite Extrusion of Mount Mishennaya, Kamchatka, and Its Age

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Abstract—The hornblende andesite extrusion of Mount Mishennaya belongs to the andesite subcomplex of the Avacha Neopleistocene–Holocene basalt–andesite volcanic complex. The Mishennaya dome belongs to the extrusive areal field found on the north bank of Avacha Creek. It is believed that the subcomplex took a long time to develop from the Early to Late Neopleistocene. Three K–Ar age determinations of the Mishennaya andesites have been made using a hornblende monofraction for one determination and the nonmagnetic fraction of the rocks for the other two. The resulting age values are 0.60, 0.57, and 0.59 Myr. These are consistent with previous paleomagnetic determinations and with results from fission track analysis (0.7 Myr).

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THE OBJECT OF STUDY

Mount Mishennaya (382 m) looms over downtown Petropavlovsk-Kamchatskii (Fig. 1). Its domelike summit can be seen from nearly all sides: from the east, i.e., from the ocean; and from the west and south, i.e., from Avacha Creek. The geological structure and rock composition of this mount are discussed in a number of reports stored in territorial geological collections. The Mishennaya andesites were studied as possible construction materials in the 1930–1950s. As a result it was determined that their composition and properties make it possible to use them as a filler for acid towers and as raw material for silicate cement. Data on the geological structure of this rock massif and its environs can be found in the State Geological Map, scale 1:200000 [2,

10] and intermediate-scale 1 : 50000 mapping data acquired in the later half of the 20th century. E.N. Grib and colleagues [4, 5] discuss the geological setting, composition, and origin of the Mishennaya andesites, and this detailed information on the andesite petrographic and chemical composition is used in the present study.

This paper is based on factual materials acquired during recent geological surveys [10, 11] and on some K–Ar isotope determinations made at the Laboratory of Isotope Geochemistry and Geochronology at the Geological Institute of the Russian Academy of Sciences.

The summit and flanks of Mount Mishennaya are subject to intensive anthropogenic factors. Around its base are residential houses, a broad winding road is cut



Fig. 1. Mount Mishennaya viewed from west-southwest, from the village of Seroglazka. Photographed by V.S. Sheimovich.

into its flanks, while the summit has tall television retransmitters and many-storied masonry buildings for industrial production and housing. Large amounts of construction materials have been expended to build these structures, viz., rubble, sand, concrete, which hide the bedrock andesites of the summit. One of the present authors had the good fortune to make frequent visits on the summit before this construction boom. He discovered several areas of fumarole-altered rock which were isometric in shape and as large as 2 m across. The gray andesites found in the areas are bleached, light yellow in color, they are opalized, argillized, and ferruginate. The fact that such areas were preserved contradicts the notion of a considerable (as much as 150 m) erosional truncation of the summit [5] and its old age. The presence of a chill zone in the andesites on the uppermost summit is also at variance with the idea of a deep erosional truncation, but rather provides evidence of a natural surface untouched by erosion and abrasion at the dome summit. The presence of these areas, along with the earlier-stated opinion that hot avalanche deposits laden with andesite blocks may be situated at the southwestern base of the mount, may indicate a comparatively young age of the dome.

FORMULATION OF THE PROBLEM

The supposed young age of this volcanic edifice raises the problem of the possible hazard that may result from it. That Mount Mishennaya is of volcanic origin is questioned by no one. However, the associated potential hazards have not been studied, since the andesite dome is believed to be of very old origin. However, the notorious example of the disastrous eruption from the Bezmyannyi andesite extrusive volcano which took place after a repose period of over two thousand years [3], in addition to the fact that the dome stands in the center of an urban center, makes the issue one of current interest.

THE GEOLOGICAL STRUCTURE OF THE ENVIRONS OF AVACHA CREEK

Recent geological surveys [10] carried out around Avacha Creek have refined the geological settings of the extrusive andesites of which the Mishennaya dome consists (Fig. 2). According to geophysical data [7, 11], a high-density metamorphic complex lies below 5–6 km depth, at the bottom of the upper crust (Fig. 2b).

A density modeling study suggested the existence of an erratic mantle block directly under Avacha Volcano. That mantle complex is overlain by strongly faulted volcanogenic–sedimentary deposits of the Upper Cretaceous Nikolskii sequence which contain gabbro-dolerite bodies. These formations seem to be allochthonous. The pre-Cenozoic rocks are cut through and overlain by rocks of the Zavoikovskii volcanic complex which includes both a cover facies (basalt–andesite, andesite, and pyroclastic deposits) and subvolcanic bodies (stocks and dikes of the same composition). The K–Ar age of the Zavoikovskii complex, 14–16 Myr, corresponds to the Miocene [9], while the pelecypod remnants collected in the pyroclastic deposits indicate an Oligocene–Miocene age [10]. No Upper Pliocene to Early Pleistocene deposits could be found, as previously indicated [2, 5], to lie in their place.

All the pre-Quaternary formations referred to above are overlain by effusive pyroclastic deposits and penetrated by their extrusive and subvolcanic analogues of the Neopleistocene–Holocene basalt–andesite complex.

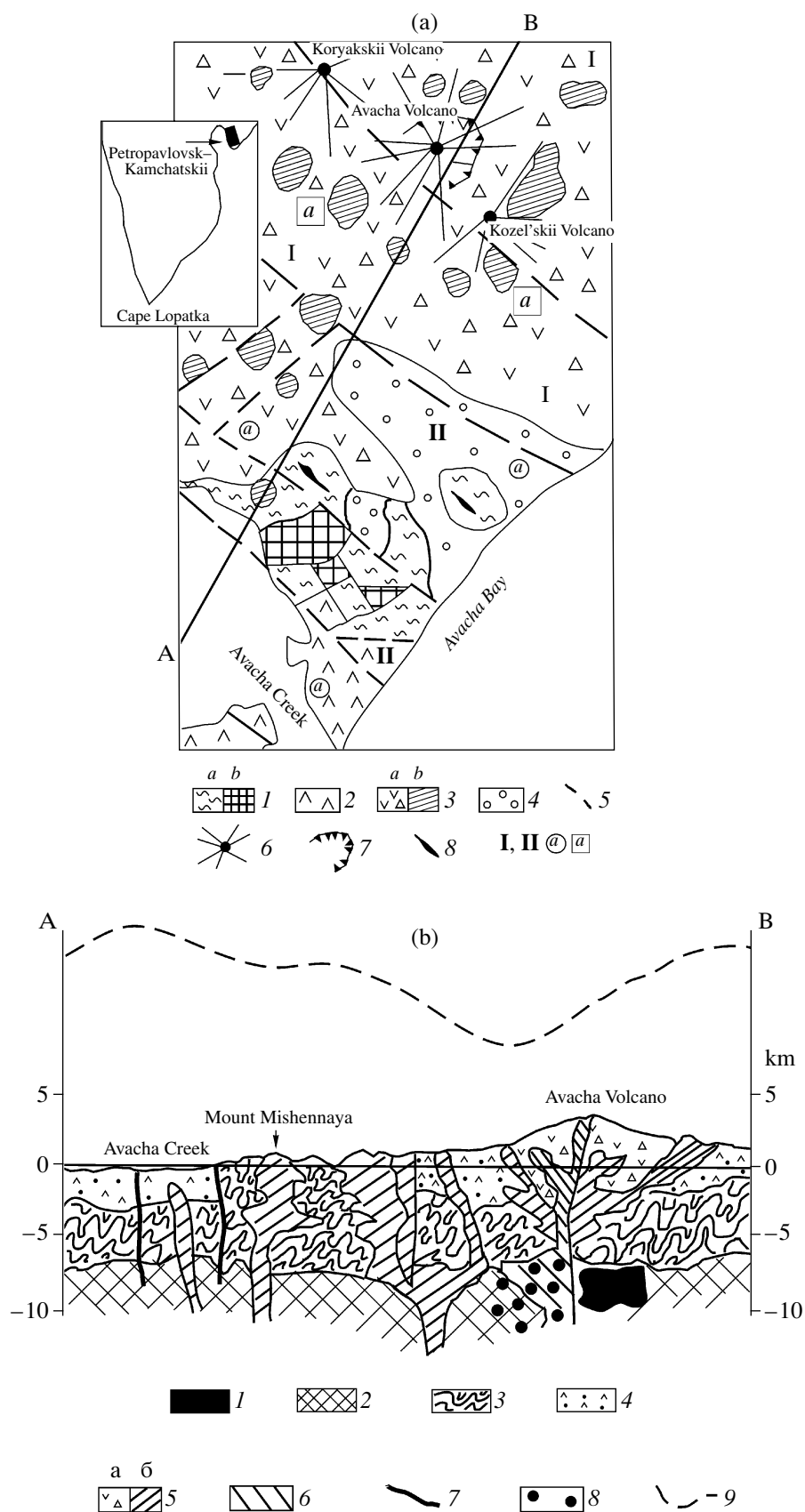
It can be seen from Fig. 2a that the andesite extrusions on the north shore of Avacha Creek have an areal occurrence, and tend to be found in fields of the early Pleistocene phase of the Avacha complex. Figure 2b displays the deep structure of the area of study derived by density modeling [11]. It appears that the volcanic andesite bodies (the root parts of the extrusions) have replaced much of the basement and may compose an independent subcomplex evolving in parallel with the volcanic massifs of Avacha, Koryakskii, and Kozel'skii volcanoes.

Structurally speaking, the area north of Avacha Creek lies in two northwest-trending zones. The Avacha–Koryakskii volcanic segment lies in the South Valaginskii block zone adjacent to the Malki–Petropavlovsk block zone. The South Valaginskii zone is represented in the area of study by the Avacha graben which is bounded on the south by the Avacha horst of the Malki–Petropavlovsk zone. It is in the Avacha horst that Mount Mishennaya and several extrusions are situated.

THE MISHENNAYA ANDESITES

The morphology and geological structural setting of the Mishennaya dome are described in some detail in [5], where one will also find a detailed characterization

Fig. 2. Geological structure of the Avacha Creek environs: (a) map of geological structure, scale 1 : 500000; (1) Upper Cretaceous rocks: ((a) volcanogenic–sedimentary and (b) subvolcanic bodies); (2) Oligocene/Miocene volcanogenic deposits; (3) Neopleistocene and Holocene formations of the Avacha basalt–andesite complex ((a) volcanogenic deposits, (b) subvolcanic bodies and extrusions); (4) Neopleistocene and Holocene alluvial and glacial deposits; (5) tectonic faults; (6) Neopleistocene and Holocene volcanoes; (7) scarp of the Avacha somma; (8) main trends of folded features. (I) South Valaginskii block zone; (II) Malki–Petropavlovsk folded block zone; (a) (in a circle) Avacha horst; (a) (in a square) Avacha graben; (b) geologic section derived by density modeling [10]; (1) high-density upper mantle (?) rocks; (2) metamorphic rocks; (3) Mesozoic volcanogenic–sedimentary rocks; (4) Oligocene and Miocene volcanogenic–sedimentary rocks; (5) Neopleistocene and Holocene andesite–basalt rocks ((a) cover facies, (b) subvolcanic bodies and extrusions); (6) Holocene subvolcanic bodies; (7) faults; (8) crustal volumes with lower density and lower compressional velocity; (9) gravity curve.



of the chemical and petrographic composition. Plagioclase and hornblende phenocrysts were examined by a microanalyzer to yield the compositions of these phenocryst zones and of the bulk of the andesites. For this reason we only quote the bulk composition of the extrusive andesites (Table 1).

Mount Mishennaya is situated near the northeast bank of Avacha Creek. The dome has a relative height of 300 m, and its base is 1 by 2 km. The summit is composed of gray andesites which typically contain black hornblende phenocrysts as long as 1 cm. In chill zones the gray rocks acquire a rosy, crimson color. They are either irregular blocks or are block-faulted, and are exposed near the summit 50–100 m below it. The andesites penetrate weakly metamorphosed sandstone, aleurolite, and argillite in the lower subsequence of the Nikolskii sequence, supposed to be of Upper Cretaceous age. The thick chill zone on the andesites, as well as loosely lying crimson-colored hornblende andesite blocks in a cliff on the shore of the creek near the southern base of the mount, which several investigators believe to be fragments of hot avalanche deposits, all point to an extrusive origin of the summit. Paleomagnetic studies [1] show that the blocks were incandescent at the time of the avalanche. Our predecessors [4, 5] in their discussion of the Mishennaya dome were unnecessarily emphatic in contrasting the notions and phenomena of 'extrusions' and 'subvolcanic bodies', which in our view should not be so contrasted. For example, one can observe dikes on the somma of Avacha Volcano that have been exposed and become extrusions.

By the modern petrochemical classification, the Mishennaya rocks are most similar to normal andesites [8, p. 85], while mineralogically they are typical hornblende andesites with a phenocryst content of up to 45%. The andesite texture is seriate porphyritic, the groundmass has a microfelsitic texture. The phenocrysts are dominated by andesine labradorite (27–30%), basaltic hornblende being present in smaller amounts (16–22%). The prevailing phenocryst size is 0.4–1.5 mm. The hornblende crystals have a zonal structure. Central and peripheral zones are frequently replaced with a fine crystalline aggregate of ore material, pyroxene and magnetite. The ore minerals include magnetite, the accessory ones are represented by apatite. The felsitic groundmass has a chemical composition (Table 1) of the classic plagioryholite [5; 8, p. 94]. This unusually acidic composition of the groundmass is explained by the presence of silicic-acid minerals, viz., tridymite and cristobalite. The xenoliths in the andesites include amphibolites (outliers of the crystalline basement) and fragments of Nikolskii sedimentary rocks, are all within 1 cm in diameter.

As to the general structural setting of the dome, there is also a point on which we do not agree with our predecessors as a matter of principle. It consists in a different view of the origin of the pyroclastic andesite

Table 1. Chemical analyses of andesites from Mount Mishennaya, and from Avacha and Kozel'skii volcanoes, percent by weight

Components	1(9)	3(2)	15	12	13	14
1	2	3	4	5	6	7
SiO ₂	56.26	75.67	57.59	56.24	56.70	57.76
TiO ₂	0.80	0.18	0.54	0.83	0.63	0.75
Al ₂ O ₃	18.60	14.03	17.98	19.09	19.16	19.45
Fe ₂ O ₃	4.54	—	3.58	2.36	2.43	3.72
FeO	2.80	1.13	3.83	4.88	3.68	3.66
MnO	0.18	0.07	0.20	0.16	0.16	0.20
MgO	3.15	0.35	3.18	3.48	2.88	2.46
CaO	8.16	3.05	8.06	8.00	7.86	7.91
Na ₂ O	3.20	4.01	2.52	3.27	3.82	3.75
K ₂ O	0.93	1.91	1.28	0.78	0.57	0.60
P ₂ O ₅	0.07	—	0.03	0.17	0.16	0.19
SO ₃	—	—	—	—	—	0.1
H ₂ O [−]	0.20	—	0.33	0.08	—	0.3
H ₂ O ⁺	0.46	—	0.69	0.28	—	0.1
CO ₂	—	—	0.08	—	—	0.1
p.p.m.	—	—	—	—	1.80	—
Total	99.35	100.38	99.89	99.62	99.85	99.85

Note: 1(9) denotes average composition of Mishennaya andesites (parentheses enclose the number of analyses) after [5]; 3(2) denotes the averaged microlog analysis of andesite groundmass after [5]; 15 denotes Mishennaya andesite; 12 is andesite sampled from the summit of Avacha Volcano (the 1991 eruption); 13 is andesite from the Avacha Volcano somma; 14 is the andesite from Kozel'skii volcano; analyses 12, 13, 14, and 15 are after [10].

deposits on the north bank of Avacha Creek which are considered by Grib et al. [5], along with I.V. Melekestsev [3], to be deposited by a directed explosion and other phenomena associated with the formation of the Avacha somma. Their opinion is that these deposits overlie the Mishennaya andesites. The ¹⁴C age as determined from organic matter found in the bottom of the pyroclastic cover is 29900 ± 900 years [3]. These deposits contain evident andesite domes having similar compositions to the debris apron (202 m altitude, andesite bedrock exposures in the villages of Sero-glazka and Mokhovaya, hot contacts of the andesites with pyroclastic deposits). As well, geophysical survey data provide evidence of magma bodies at depths similar to the Mishennaya andesites; all this combined evidence shows that part of these pyroclastic deposits is related to an in situ discharge of andesite melt onto the surface. In this connection it is of interest to note the difference in chemical composition between the Mishennaya andesites on the one hand and the andesites of the Avacha and Kozel'skii volcanoes on the other

Table 2. K–Ar age for hornblende phenocrysts and nonmagnetic fraction of Mishennaya andesite

Laboratory number of sample	Material analyzed	Content of K, %	Content of $^{40}\text{Ar}_{\text{rad}}$, $\text{mm}^3 \text{g}^{-1}$ ($\times 10^5$)	Content of $^{40}\text{Ar}_{\text{rad}}$, $\text{mm}^3 \text{g}^{-1}$ ($\times 10^5$) corrected for the background experiment	Age, Myr
895	Amphibole	0.34	0.99	0.750	0.60
896	Nonmagnetic fraction	0.62	1.52	0.631	0.57
896	Nonmagnetic fraction	0.62	1.57	0.650	0.59

Note: Age was calculated using the constants $\lambda_e = 0.581 \times 10^{-10} \text{ yr}^{-1}$, $\lambda_\beta = 4.962 \times 10^{-10} \text{ yr}^{-1}$, $^{40}\text{K}/\text{K} = 1.167 \times 10^{-4}$ [12].

(Table 1), the former andesites having a higher potassium content [5, 10]. The concentration of K_2O in volcanic andesites is 1.5–2 times lower than that in our andesites. The high potassium concentration in the Mishennaya dome rocks is due to a comparatively high concentration of K_2O (1.91%) in their felsitic groundmass.

There are thus both geological–structural and petrochemical features that suggest the presence of an independent andesite complex containing the extrusions on the north shore of Avacha Creek, among which is Mount Mishennaya.

ON THE AGE OF THE MISHENNAYA ANDESITES

The current views of the age of the Mishennaya extrusion so far find little support in concrete data. All investigators who studied the dome since the time of A.N. Zavaritskii considered and continue to consider the age to be Pleistocene. This hypothesis stems from the opinion that the andesites are similar to the extrusions of the Avacha and Kozel'skii volcanoes [2, 5]. This opinion was later corroborated by paleomagnetic determinations showing that the Mishennaya andesites are not magnetized in the reverse sense [1, 5]. Based on the relationship between the dome under discussion and ancient marine terraces, which is very uncertain in our opinion, I.F. Delemen' hypothesizes that the extrusion is older than 0.2 Myr [5]. V.L. Koshkin in 1986 determined the andesite age to be 0.7 ± 0.2 Myr by fission track analysis applied to apatite [10].

If our hypothesis of a genetic relationship between the pyroclastic andesite deposits and the andesite extrusions on the north bank of Avacha Creek is correct, then the time when the pyroclasts were deposited is also the time when the extrusions formed, i.e., is 29900 ± 900 years [3].

The available data set thus suggests that the time of emplacement for the andesite extrusions was rather long, covering nearly all of the Neopleistocene.

Potassium–argon dating. Availing ourselves of a slightly increased potassium content in the Mishennaya andesites, we decided to make several K–Ar age determinations using the hornblende monofraction and the nonmagnetic fraction, i.e., actually using the andesite

groundmass (Table 1). The content of K_2O in the hornblende (the content of K_2O is 0.4–0.5 wt % in the central and intermediate zones of phenocrysts and 0.2–0.3 wt % in the marginal zones [5]) is such as to place the sample of the monofraction of that mineral at the utmost limit where the classical potassium–argon dating technique can still be used. Plagioclase phenocrysts contain extremely low amounts of potassium (between 0.08 and 0.2 wt %, according to [5]), while the potassium content in the groundmass is twice as high as that in the hornblende. These data are shown in Table 2 along with measurements of the content of radioactive ^{40}Ar .

The preparation of samples by the potassium–argon dating technique. The 0.16–0.2-mm fraction obtained by putting a fragmented sample through sieves was inspected under a binocular microscope to select an monomineral amphibole fraction. It was analyzed separately after dark minerals were eliminated. The results are displayed in Table 2.

The content of radiogenic argon was measured by an MI 1201IG mass spectrometer using the isotope dilution analysis method (the tracer (^{38}Ar) purity was 95.4%). The measurement accuracy was checked by repeated analyses of the samples and by the consistency between analyses applied to a standard Dacite sample ($0.00288 \text{ mm}^3 \text{g}^{-1} ^{40}\text{Ar}$). The error based on the standard sample was $\pm 1.5\%$. However, the consistency shown upon repeated measurements is naturally much worse, about 3.5%.

When samples of such a low concentrations of radiogenic argon are analyzed, one needs to consider the contribution of instrument noise. This was done by making numerous background experiments, i.e., experiments involving all the procedures of extraction and purification of argon from the sample, but without melting the sample. The instrumental background is due to the release of sorbed radiogenic argon from previously analyzed samples on the inner surfaces of the vacuum system and getters. The experimental background was considerable, about $2 \times 10^{-7} \text{ mm}^3$. Its contribution to the measured radiogenic argon is ten (the host rock) to forty (amphibole) percent. The percentage of argon in the air was not above 60% for all the samples.

The content of potassium was determined by the atomic absorber to within 1.5%.

Based on the above, the dating accuracy is here estimated as $\pm 0.15\text{--}0.2$ Myr.

CONCLUSIONS

Geological evidence indicates times in excess of 0.2 Myr for the age of the extrusion [5]. Sheimovich [10] obtained an age value by fission track analysis applied to apatite (in the case under consideration this is contained in the groundmass): 0.7 ± 0.2 Myr. Naturally enough, a single age determination based on one of the minerals in the extrusion cannot provide reliable support for the time at which the extrusion formed. This circumstance led us to isolate amphibole from the bulk sample, this being one of the most stable minerals regarding the loss of argon [6] from the rock that contains it and apatite. It may also be supposed that amphibole is an element of the older rocks at the base of the volcano that were trapped during the formation of the extrusion.

However, our measurements show that the closing of potassium–argon systems in rock components took place at the same time. It is highly unlikely that samples having twofold differences in potassium content and different capabilities of argon containment under identical conditions, could undergo processes that would make their ages equal.

Consequently, it may safely be asserted that the age of the rock sample analyzed equals 0.6 ± 0.2 Myr, and reflects the time of an episode during the formation of the andesite subcomplex.

REFERENCES

1. Alypova, O.M. and Timerbaeva, K.M., On Determining the Deposition Temperature of Coarse Volcanites from Their Remanent Magnetization, in *Kislyi vulkanizm* (Acidic Volcanism), Novosibirsk: Nauka, 1973, pp. 178–183.
2. Aprelkov, S.E., *Gosudarstvennaya geologicheskaya karta SSSR, masshtab 1:200000. Seriya Zapadno-Kamchatskaya. List N-57-XXVII i ob"yasnitel'naya zapiska k nemu* (State Geological Map of the USSR, Scale 1 : 200000. West Kamchatka Series. Sheet N-57-XXVII and an Explanatory Note), Moscow: Nedra, 1965.
3. Braitseva, O.A., Melekestsev, I.V., Ponomareva, V.V., et al., The Age of Active Volcanoes in the Kuril–Kamchatka Region, *Vulkanol. Seismol.*, 1994, no. 4/5, pp. 5–32.
4. Grib, E.N., The Andesites of Mount Mishennaya, *Voprosy geografii Kamchatki*, 1985, issue 9, pp. 130–133.
5. Grib, E.N., Delemen', I.F., and Fedotov, S.A., The Structure, Composition, and Origin of the Andesite Dome of Mount Mishennaya, Kamchatka, *Vulkanol. Seismol.*, 1986, no. 6, pp. 29–44.
6. Damon, P.E., Potassium–argon Dating of Igneous and Metamorphic Rocks with Applications to the Basin Ranges of Arizona and Sonora, in *Radiometric Dating for Geologists*, Hamilton, E.I. and Farquhar, R.M., Eds., Interscience Publishers, 1968, pp. 1–71.
7. Mishin, V.V., The Geological and Geophysical Structure of Southern Kamchatka, *Tikhookeanskaya Geologiya*, 1996, no. 1, pp. 110–119.
8. *Petrograficheskii kodeks. Magmaticheskie i metamorficheskie obrazovaniya* (Petrographic Code. Igneous and Metamorphic Formations), St. Petersburg: VSEGEI, 1995.
9. Sheimovich, V.S. and Golovin, D.I., The Structure of the Miocene Andesite Formation of Southern Kamchatka and Its Radiologic Age, *Vulkanol. Seismol.*, 1998, no. 3, pp. 3–11.
10. Sheimovich, V.S., *Gosudarstvennaya geologicheskaya karta RF, masshtab 1 : 200000. Seriya Yuzhno-Kamchatskaya. Listy N-57-XXI, N-57-XXVII, N-57-XXXIII i ob"yasnitel'naya zapiska k nim* (State Geological Map of RF, Scale 1 : 200000. Southern Kamchatka Series. Sheets N-57-XXI, N-57-XXVII, N-57-XXXIII, and an Explanatory Note), Moscow: 2000.
11. Sheimovich, V.S. and Sidorov, M.D., The Basement Structure of a Volcanic Belt: Southeastern Kamchatka, *Vulkanol. Seismol.*, 2000, no. 5, pp. 28–35.
12. Dalrymple, G.B., Critical Tables for Conversion of K–Ar Ages from Old to New Constants, *Geology*, 1979, vol. 7, no. 11, pp. 558–560.